73rd MORSS CD Cover Page

712CD

UNCLASSIFIED DISCLOSURE FORM CD Presentation

For office use only 41205

21-23 June 2005, at US Military Academy, West Point, NY

Please complete this form 712CD as your cover page to your electronic briefing submission to the MORSS CD. Do not fax to the MORS office.

Author Request (To be completed by applicant) - The following author(s) request authority to disclose the following presentation in the MORSS Final Report, for inclusion on the MORSS CD and/or posting on the MORS web site.

Name of Principal Author and all other author(s): William Todd
Alan Harvey

Principal Author's Organization and address:
SAIC

Phone:_

Fax:__
Email:_

Original title on 712 A/B:__MODELING RUNWAY DAMAGE AND REPAIR USING THE SIMULATION OF LINEAR INTERDICTION, CRATERING, AND REPAIR (SLICR) MODEL

Revised title:_N/A

Presented in (input and Bold one): (WG 15, CG___, Special Session ___, Poster, Demo, or Tutorial):

This presentation is believed to be:
UNCLASSIFIED AND APPROVED FOR PUBLIC RELEASE

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **23 JUN 2005**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Modeling Runway Damage and Repair using the Simulation of Linear Interdiction, Cratering, and Repair (SLICR) Model**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **SAIC**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES **See also ADM201946, Military Operations Research Society Symposium (73rd) Held in West Point, NY on 21-23 June 2005 . , The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**39**	

Modeling Runway Damage and Repair using the Simulation of Linear Interdiction, Cratering, and Repair (SLICR) Model

73rd MORS Symposium

June 23, 2005

William Todd, Allen Harvey and Frank Lewis
(SAIC) (SAIC) (OSD/PA&E)

Objective and Approach

Objective:

Develop methodologies to determine effectiveness of a multiple sub-munition attack against runways.

Approaches:

–Statistical analysis to provide heuristic model

–Monte Carlo simulation (SLICR model)

Contents

Problem Description

Determine the effectiveness of a missile strike against a runway with each missile containing multiple penetrator sub-munitions.

- Airfield is defined by:
  - Length and width of runways/taxiways
  - Length and width of minimum operating strip (MOS)

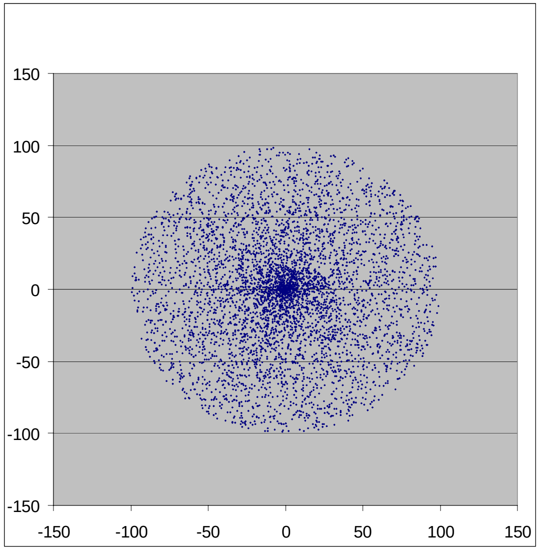
- Missile strike is defined by:
  - Missile CEP
  - Total number of sub-munitions (sub-munitions per missile time number of missiles)
  - Sub-munition crater diameter
  - Sub-munition distribution pattern

Sub-munition Distribution Methods

Uniform sub-munition / penetrator PATTERNS can be modeled in two ways:

Uniform **Radial** Distribution

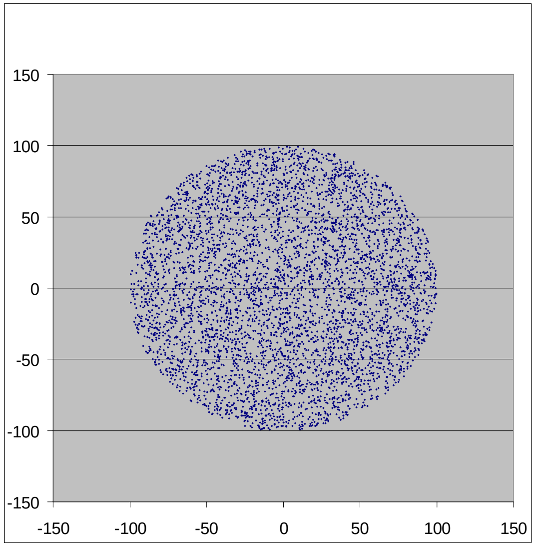
- Random radius less than pattern radius and random angle
- Produces concentration of points near center



Uniform **Radial** Distribution of 5000 points

Circular **Uniform** Distribution

- Random X and Y coordinates
- Eliminate points outside pattern radius
- Uniform density of points



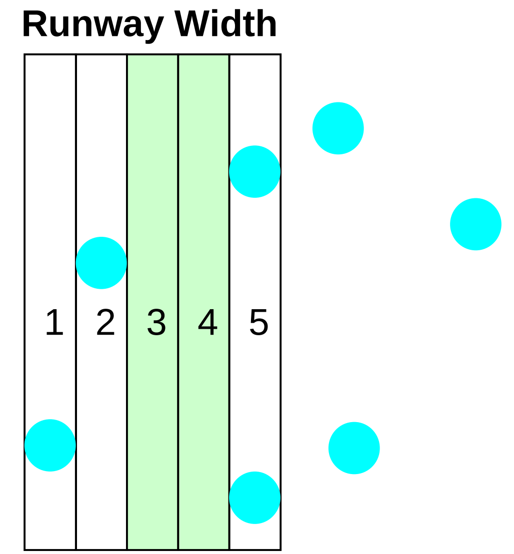
Circular **Uniform** Distribution of 5000 points

Contents

- Problem description
- ⇨ Runway closing heuristic/ Statistical model
- SLICR model description and methodology
  - Probability of closing runway
    - Target flexibility
    - Attack strategies
  - Time required for runway repair
  - Missile defense
- Model Demonstration

Runway Closing Heuristics
Statistical Analysis

- Divide the runway into **T** sections, each with a width equal to the crater diameter.
- Define **L** as the number of contiguous sections required to meet the minimum width requirements.
- Define **N** as the total number of penetrators.



Problem becomes:

Determine the probability that a missile strike with N penetrators will leave at least L contiguous sections of runway clear.

$$T = \frac{\text{runway width}}{\text{crater diameter}} = 5$$

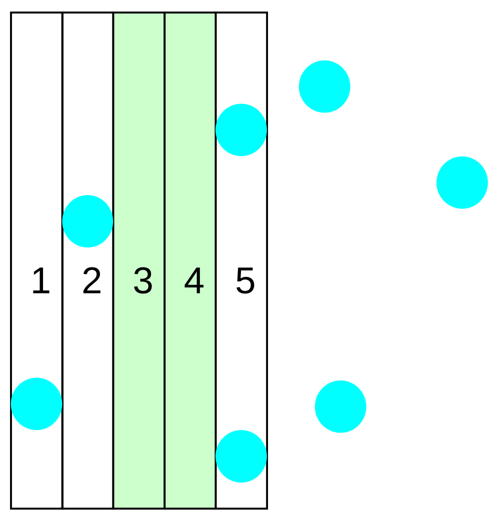
$$L = \frac{\text{minimum required width}}{\text{crater diameter}} = 2$$

$$N = 7$$

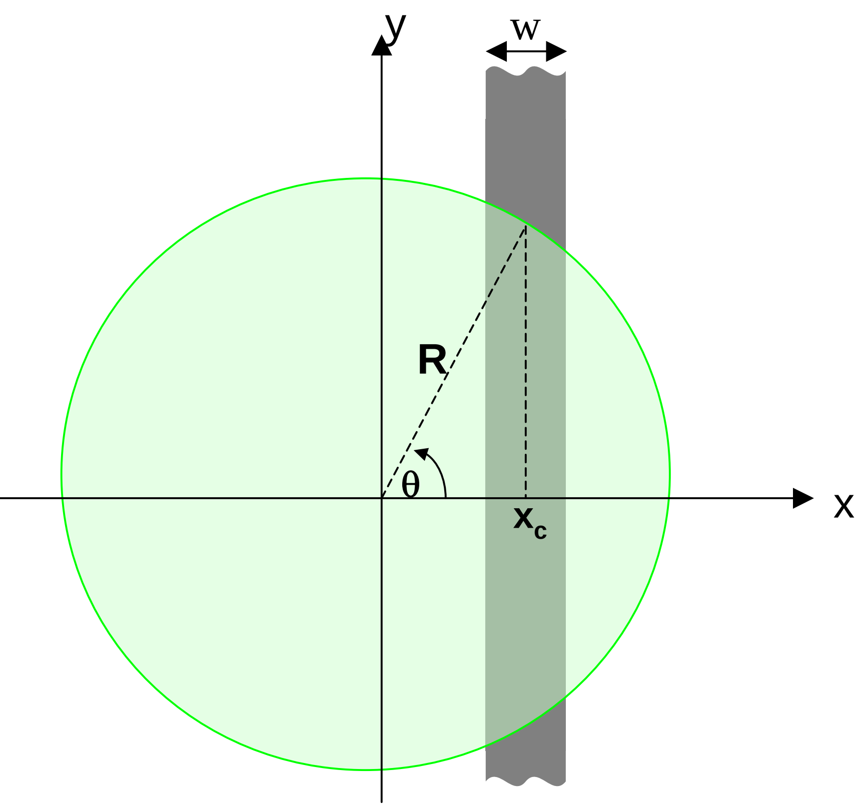
Runway Closing Heuristics
Statistical Analysis

Break the problem into three parts:

1. Determine the probability that **m** penetrators will hit the runway, where $0 \leq \mathbf{m} \leq \mathbf{N}$
2. Determine the probability that if **m** penetrators hit the runway at least one penetrator will hit exactly **S** of the **T** sections, where $0 \leq \mathbf{S} \leq \mathbf{T}$.
3. Determine the probability that if **S** of **T** sections are hit there will be **L** contiguous open sections.



Runway Closing Heuristics
1. Sub-munitions On Target



w = runway width

R = radius of weapon pattern

x_c = x-coord of runway center (miss distance)

Let $\mathbf{P_x}$ be the fraction of penetrators that hit the runway for a given miss distance $\mathbf{X_c}$

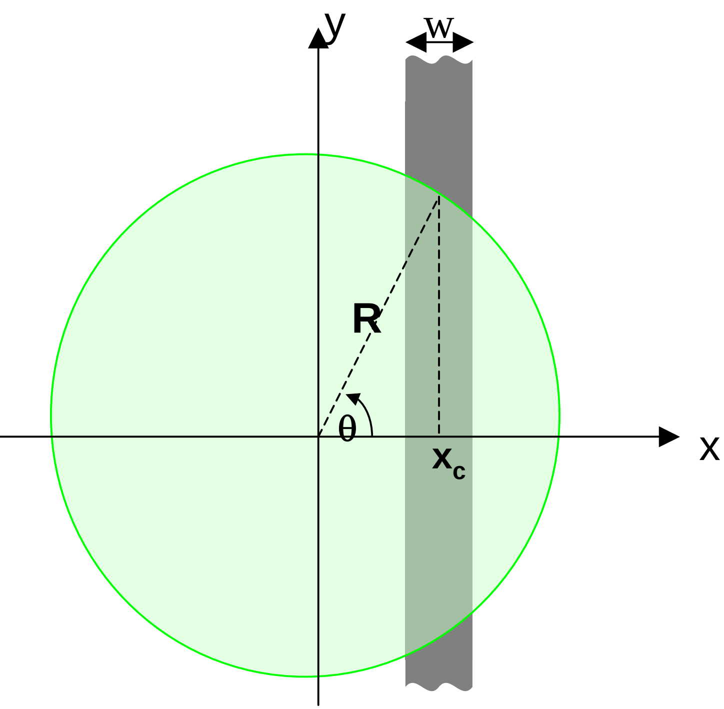
$$\mathbf{P_x} = \frac{\text{Area of Affected Runway}}{\text{Area of Weapon Pattern}}$$

$$\approx \frac{2wR\sin\theta}{\pi R^2} = \frac{2w\sqrt{R^2 - {x_c}^2}}{\pi R^2}$$

This approximation requires R > w and a circular uniform distribution

Runway Closing Heuristics

1. Sub-munitions On Target



The probability that a given penetrator will hit the runway, $\mathbf{P_A}$, is found by multiplying the probability $\mathbf{P_x}$ by the probability that the miss distance will be $\mathbf{X_c}$ (normal distribution along X based on the CEP) and integrating over all X

$$P_A = \frac{2w}{\pi \cdot R^2 \sigma \cdot \sqrt{2\pi}} \int_{-R}^{R} \sqrt{R - x^2}\, e^{-R^2/4\sigma^2} dx \qquad \text{where} \qquad \sigma = \frac{CEP}{\sqrt{2 \ln 2}}$$

$$P_A = \frac{w}{\sigma \cdot \sqrt{2\pi}} e^{-R^2/4\sigma^2} [BesselI(0, R^2/4\sigma^2) + BesselI(1, R^2/4\sigma^2)]$$

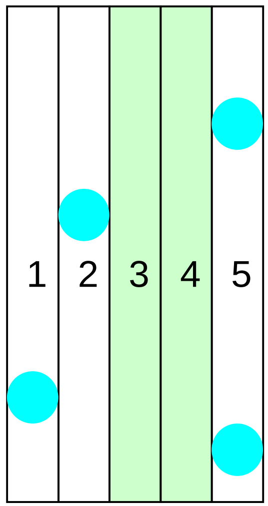
If There are **N** total penetrators, the probability that **m** of them will strike the runway is given by the m^{th} binomial coefficient of the probability P_A.

$$P_m(N) = \frac{N!}{m!(N-m)!} P_A^m (1 - P_A)^{(N-m)}$$

Runway Closing Heuristics

2. Sections Hit

Runway Width



$P_S(m,T)$ = The probability that at least one of **m** hits will land in exactly **S** of the **T** sections of the runway, with $0 \leq S \leq T$

$$P_S(m,T) = \frac{T!}{S!(T-S)!}\sum_{i=0}^{S}\frac{(-1)^i S!(S-i)^m}{i!(S-i)!T^m}$$

$P_S(4,5) = 0.576$ for $S = 3$

$P_S(N,T)$ = The probability that in an attack of **N** penetrators at least one penetrator will land in exactly **S** of the **T** sections of the runway, with $0 \leq S \leq T$

$$P_S(N,T) = \sum_{m=S}^{N} P_m(N) P_S(m,T)$$

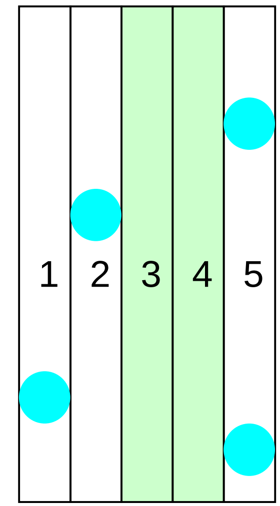
T = rwy selections = width/crater size, 5
S = rwy sections hit, 3
m = number of attempts, 4
L = number of contiguous, unhit sections, 2

Runway Closing Heuristics

3. Contiguous Open Sections

OSD/PA&E

Runway Width



$P_L(T,S)$ = Probability that there are at least **L** *contiguous open* sections when **S** of **T** sections have been hit

$$P_L\left(T,S\right)=\frac{S!\left(T-S\right)!}{T!}\sum_{i=1}^{\min\left(\frac{T-S}{L},S+1\right)}\left(-1\right)^{i+1}\frac{\left(S+1\right)!}{i!\left(S+1-i\right)!}\frac{\left(T-iL\right)!}{S!\left(T-iL-S\right)!}$$

$P_L(5,3) = 0.400$ for L = 2

$P_L(m,T)$ = Probability that there are at least **L** *contiguous open* sections if **m** penetrators hit the runway.

$$P_L\left(m,T\right)=\sum_{S=0}^{T}P_L\left(T,S\right)*P_S\left(m,T\right)$$

$P_{L=2}(4,5) = 0.440$

T = rwy selections = width/crater size, 5
S = rwy sections hit, 3
m = number of attempts, 4
L = number of contiguous, unhit sections, 2

Runway Closing Heuristics
Cutting the Runway

$P_L(N,T)$ = Probability that **N** penetrators shot at the runway will **NOT** cut the runway.

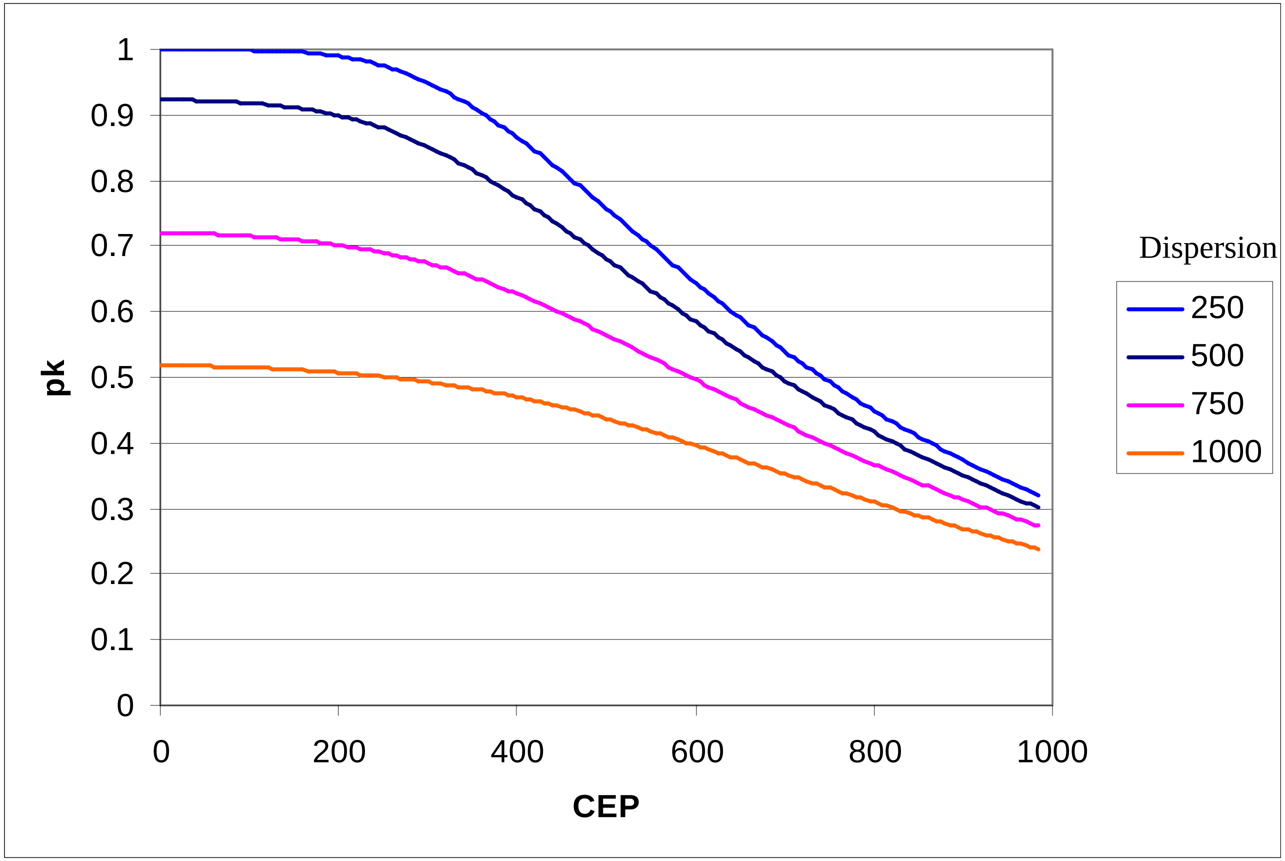
$$P_L(N,T) = \sum_{S=0}^{T} P_L(T,S) * P_S(N,T)$$

Probability that **N** penetrators shot **will** cut the runway is just.

$P_k = 1 - P_L(N,T)$

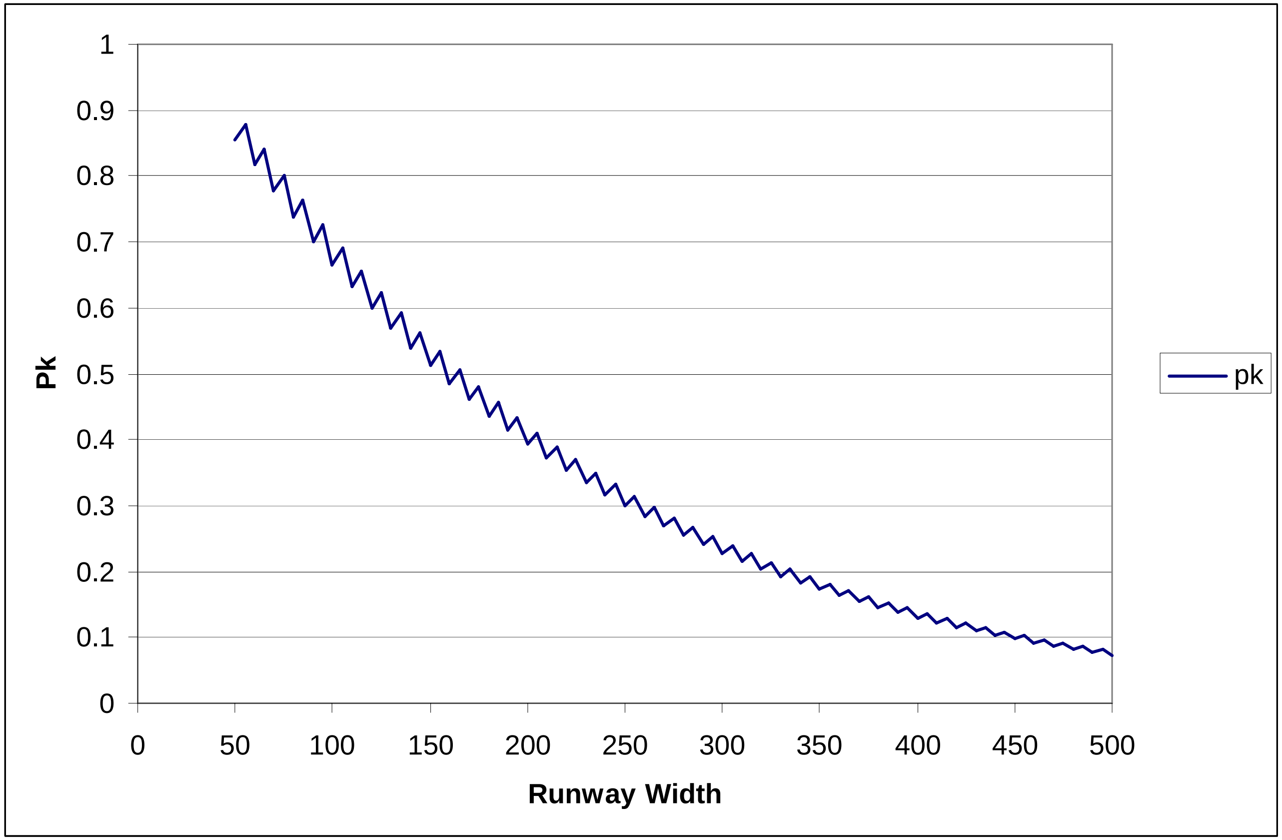
Example:	
Num penetrators =70	Runway Width =150’
Crater diameter = 10’	Min Width = 50’
Missile CEP = 150’	
Penetrator dispersion = 1000’	
Total penetrators on runway = 7	
$\mathbf{P_k = 0.51}$	

Pk as a function of CEP



Runway Width = 150
Minimum Width = 50
Crater Diameter = 10
Num Penetrators = 70

Pk as a function of Runway Width



Minimum Width = 50
Dispersion = 1000
Crater Diameter = 10
Num Penetrators = 70
CEP = 150

Contents

- Problem description
- Runway closing heuristic/ Statistical model
- SLICR model description and methodology
  - Probability of closing runway
    - Target flexibility
    - Attack strategies
  - Time required for runway repair
  - Missile defense
- Model Demonstration

SLICR Model Description

Simulation of Linear Interdiction, Cratering and Repair

- **SLICR is a Monte Carlo simulation of the probability of closing a linear target (runway, taxiway, road, etc.)**
- **Warheads can have unitary or sub-munition (penetrator) payloads**
- **INPUTS** (Primary)
  - Target length and width
  - Additional Targets, e.g., runways as separate targets or as a single target
  - Minimum Operating Segment length and width (MOS) criteria
  - Unitary or sub-munition crater diameter
  - Number of sub-munitions and dispersal radius
  - Missile CEP
  - Weapon and sub-munition reliability
  - Weapon Aimpoint Methodology
- **OUTPUTS**
  - The probability of closing the linear target as a function of the number of warheads
  - Average minimum number of craters that require repair to open a section of target that meets the MOS criteria
  - Estimated time to repair the runway, assuming various criteria
  - Effect of restrikes to reclose the runway and additional repairs needed to reopen

SLICR Model Description
Methodology

- Determine the number of cuts required
- Randomly disperse sub-munitions based on missile CEP, number of sub-munitions and dispersion
- Search the target area to see if there is any area that meets the MOS criteria
- If not, search the target area for the region that requires the fewest repairs to meet the MOS criteria
- Repeat for each Monte Carlo run

SLICR - Inputs

	A	B	C	D	E
1	**Airstrips -->**	**Airstrip 1**	**Airstrip 2**	**Airstrip 3**	**Airstrip 4**
2	**Airstrip Length**	12000			
3	**Airstrip Width**	200			
4	**Airstrip Center X**	0			
5	**Airstrip Center Y**	0			
6	**Airstrip Angle (0-360)**	0			
7	Min Length	5000			
8	Min Width	50			
9	Delivery Type	Submunitions			
10	Crater Diameter	10.00			
11	# Submunitions	70			
12	CEP	150.00			
13	Dispersion Radius	1000			
14	Distribution Method	Circular			
15	Aimpoint Method	Center of Airfield			
16	Missile Reliability	1.00			
17	Subm. Reliability	1.00			
18	Damage Goal (0-1)	0.900			
19	Number Runs (Monte Carlo)	1000			
20	Min Number Weapons/Cut	1			
21	Max Number Weapons/Cut	10			
22	# of Cuts (0 for default)	2			
23					

New Simulation

Quit Monte Carlo

Add Missiles

Distort Map Off

Reset

SLICR - Inputs

	A	B	C	D	E
1	**Airstrips -->**	**Airstrip 1**	**Airstrip 2**	**Airstrip 3**	**Airstrip 4**
2	**Airstrip Length**	12000			
3	**Airstrip Width**	200			
4	**Airstrip Center X**	0			
5	**Airstrip Center Y**	0			
6	**Airstrip Angle (0-360)**	0			
7	Min Length	5000			
8	Min Width	50			
9	Delivery Type	Submunitions			
10	Crater Diameter				
11	# Submunitions				
12	CEP				
13	Dispersion Radius				
14	Distribution Method	Circular			
15	Aimpoint Method	Center of Airfield			
16	Missile Reliability	1.00			
17	Subm. Reliability	1.00			
18	Damage Goal (0-1)	0.900			
19	Number Runs (Monte Carlo)	1000			
20	Min Number Weapons/Cut	1			
21	Max Number Weapons/Cut	10			
22	# of Cuts (0 for default)	2			
23					

Submunitions
Unitary
Dumb Bombs
Smart Bombs

New Simulation
Quit Monte Carlo
Add Missiles
Distort Map Off
Reset

SLICR - Inputs

	A	B	C	D	E
1	**Airstrips -->**	**Airstrip 1**	**Airstrip 2**	**Airstrip 3**	**Airstrip 4**
2	**Airstrip Length**	12000			
3	**Airstrip Width**	200			
4	**Airstrip Center X**	0			
5	**Airstrip Center Y**	0			
6	**Airstrip Angle (0-360)**	0			
7	Min Length	5000			
8	Min Width	50			
9	Delivery Type	Submunitions			
10	Crater Diameter	10.00			
11	# Submunitions	70			
12	CEP	150.00			
13	Dispersion Radius	1000			
14	Distribution Method	Circular			
15	Aimpoint Method				
16	Missile Reliability	[illegible]			
17	Subm. Reliability	1.00			
18	Damage Goal (0-1)	0.900			
19	Number Runs (Monte Carlo)	1000			
20	Min Number Weapons/Cut	1			
21	Max Number Weapons/Cut	10			
22	# of Cuts (0 for default)	2			
23					

Radial
Circular

New Simulation
Quit Monte Carlo
Add Missiles
Distort Map Off
Reset

SLICR - Inputs

	A	B	C	D	E
1	**Airstrips -->**	**Airstrip 1**	**Airstrip 2**	**Airstrip 3**	**Airstrip 4**
2	**Airstrip Length**	12000			
3	**Airstrip Width**	200			
4	**Airstrip Center X**	0			
5	**Airstrip Center Y**	0			
6	**Airstrip Angle (0-360)**	0			
7	Min Length	5000			
8	Min Width	50			
9	Delivery Type	Submunitions			
10	Crater Diameter	10.00			
11	# Submunitions	70			
12	CEP	150.00			
13	Dispersion Radius	1000			
14	Distribution Method	Circular			
15	Aimpoint Method	Center of Airfield			
16	Missile Reliability				
17	Subm. Reliability				
18	Damage Goal (0-1)				
19	Number Runs (Monte Carlo)				
20	Min Number Weapons/Cut				
21	Max Number Weapons/Cut	10			
22	# of Cuts (0 for default)	2			
23					

Center of Airfield
Center of Left-most Airstrip
Center of Right-most Airstri
Center of Each Airstrip
Multiple Aimpoints

Simulation
Monte Carlo
Missiles
Distort Map Off
Reset

SLICR Model Example

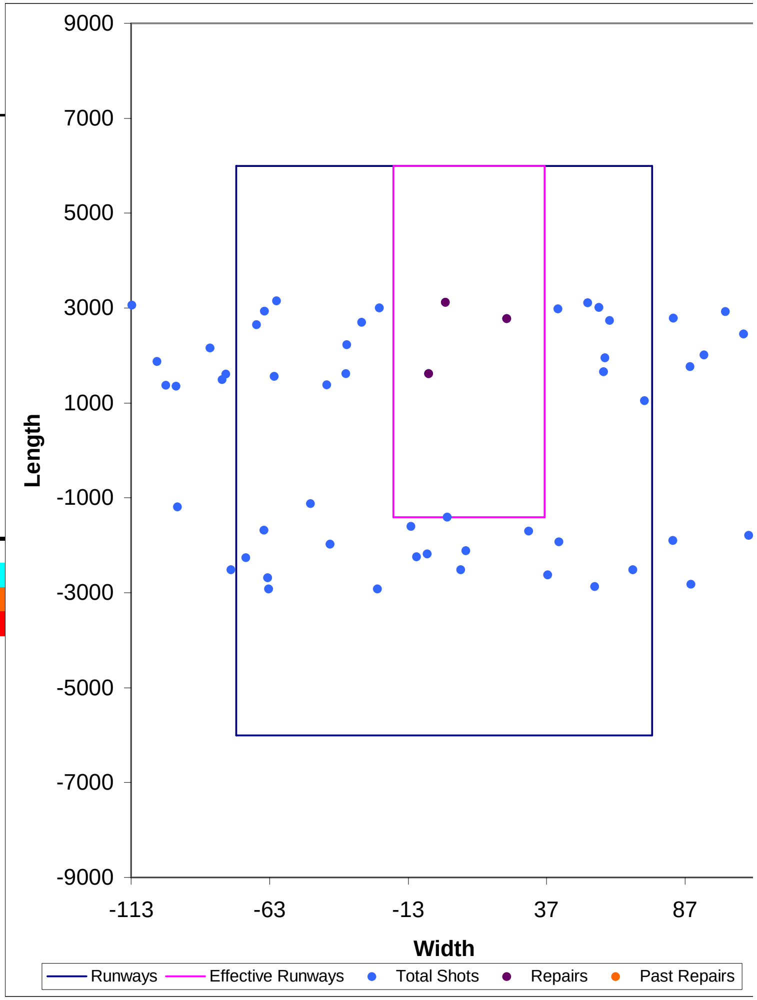
OSD/PA&E

Airstrips -->	Airstrip 1	Airstrip 2	Airstrip 3	Airstrip 4	Airstrip 5	Airstrip 6	Airstrip 7	Airstrip 8	Airstrip 9	Airstrip 10
Airstrip Length	12000									
Airstrip Width	150									
Airstrip Center X	0									
Airstrip Center Y	0									
Airstrip Angle (0-360)	0									

Min Length	5000
Min Width	50
Delivery Type	Submunitions
Crater Diameter	10.00
# Submunitions	70
CEP	150.00
Dispersion Radius	1000
Distribution Method	Circular
Aimpoint Method	Center of Airfield
Missile Reliability	1.00
Subm. Reliability	1.00
Damage Goal (0-1)	0.900
Number Runs (Monte Carlo)	1000
Min Number Weapons/Cut	1
Max Number Weapons/Cut	10
# of Cuts (0 for default)	2

New Simulation
Quit Monte Carlo
Add Missiles
Distort Map Off
Reset

Weapons per Cut	Pk	Ave. Repairs	Std. Dev. # R	Ave. Subm. on T.	Std. Subm. on Tgt
1	0.37	0.4	0.64	14.17	3.60
2	0.90	2.0	1.14	28.07	4.91
3	0.99	3.8	1.41	42.53	6.17



SLICR Model Example

Airstrips -->	Airstrip 1	Airstrip 2	Airstrip 3	Airstrip 4	Airstrip 5	Airstrip 6	Airstrip 7	Airstrip 8	Airstrip 9	Airstrip 10
Airstrip Length	12000									
Airstrip Width	150									
Airstrip Center X	0									
Airstrip Center Y	0									
Airstrip Angle (0-360)	0									
Min Length	5000									
Min Width	50									
Delivery Type	Submunitions									
Crater Diameter	10.00									
# Submunitions	70									
CEP	150.00									
Dispersion Radius	1000									
Distribution Method	Circular									
Aimpoint Method	Center of Airfield									
Missile Reliability	1.00									
Subm. Reliability	1.00									
Damage Goal (0-1)	0.900									
Number Runs (Monte Carlo)	1000									
Min Number Weapons/Cut	1									
Max Number Weapons/Cut	10									
# of Cuts (0 for default)	2									

New Simulation

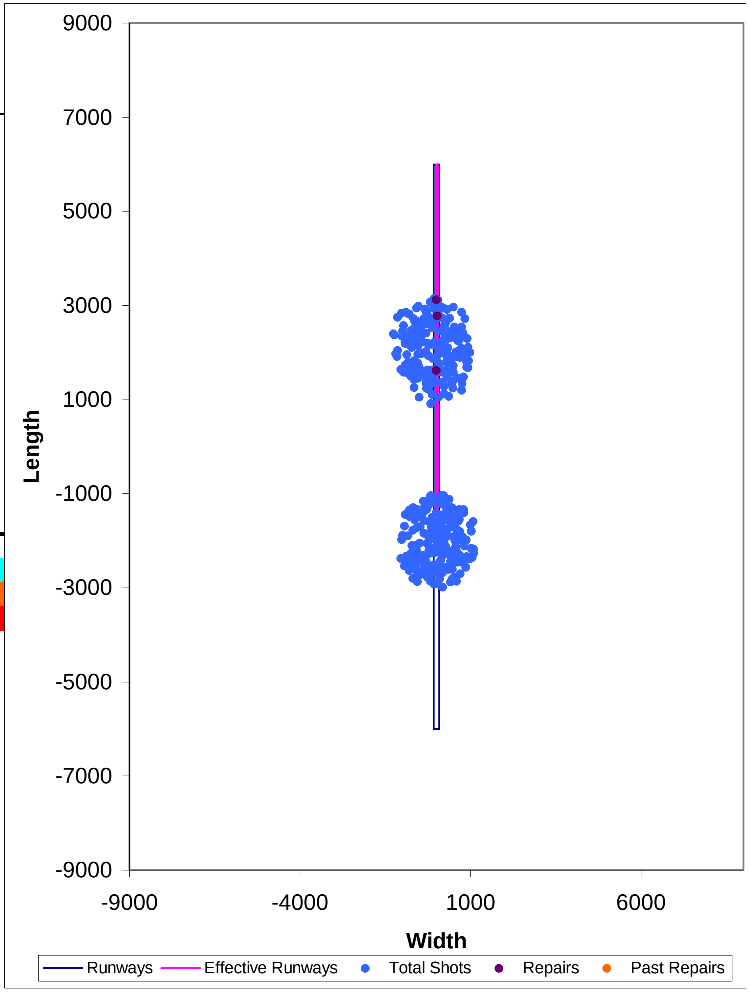
Quit Monte Carlo

Add Missiles

Distort Map On

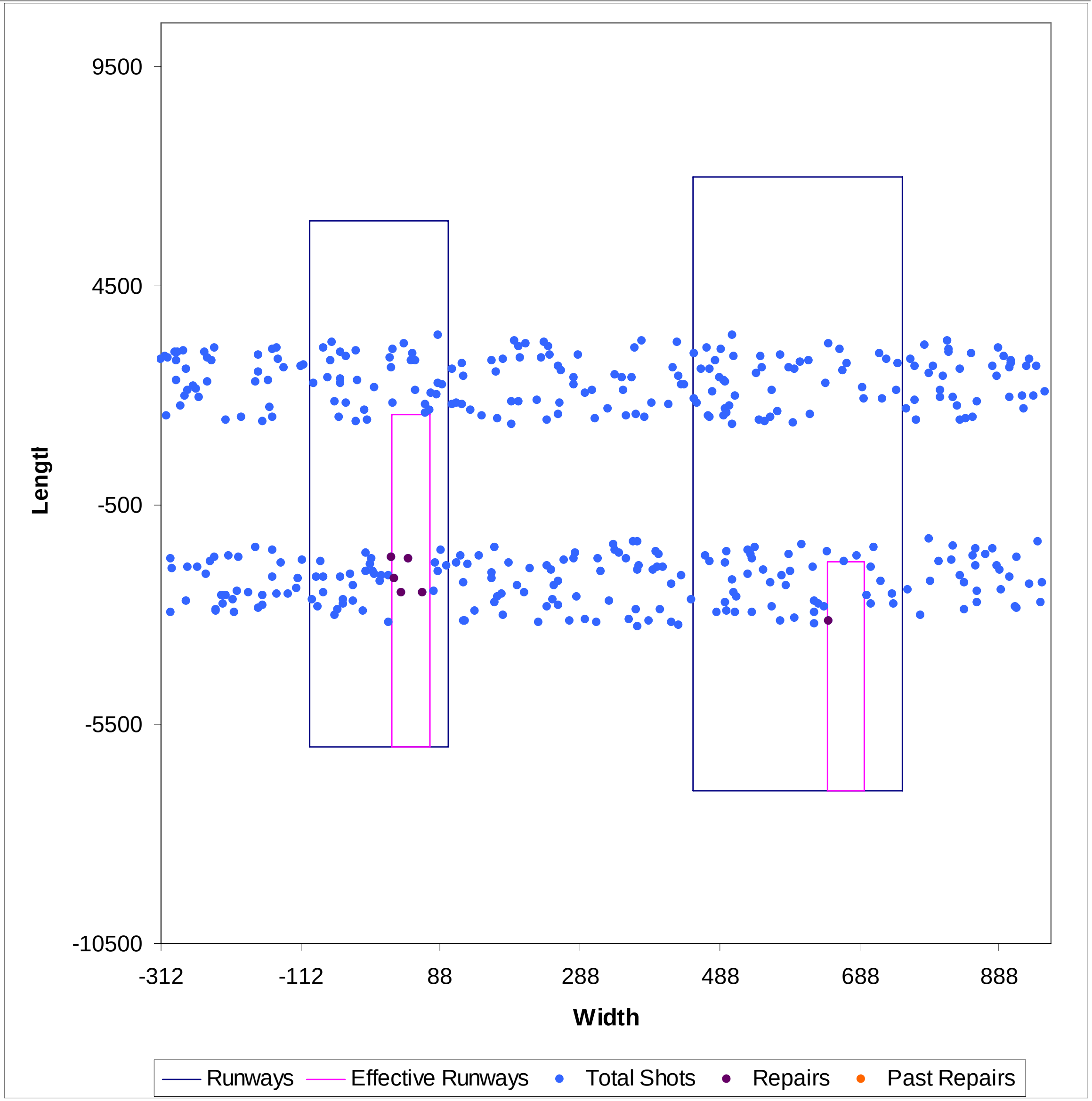
Reset

Weapons per Cut	Pk	Ave. Repairs	Std. Dev. # R	Ave. Subm. on T.	Std. Subm. on Tgt
1	0.37	0.4	0.64	14.17	3.60
2	0.90	2.0	1.14	28.07	4.91
3	0.99	3.8	1.41	42.53	6.17

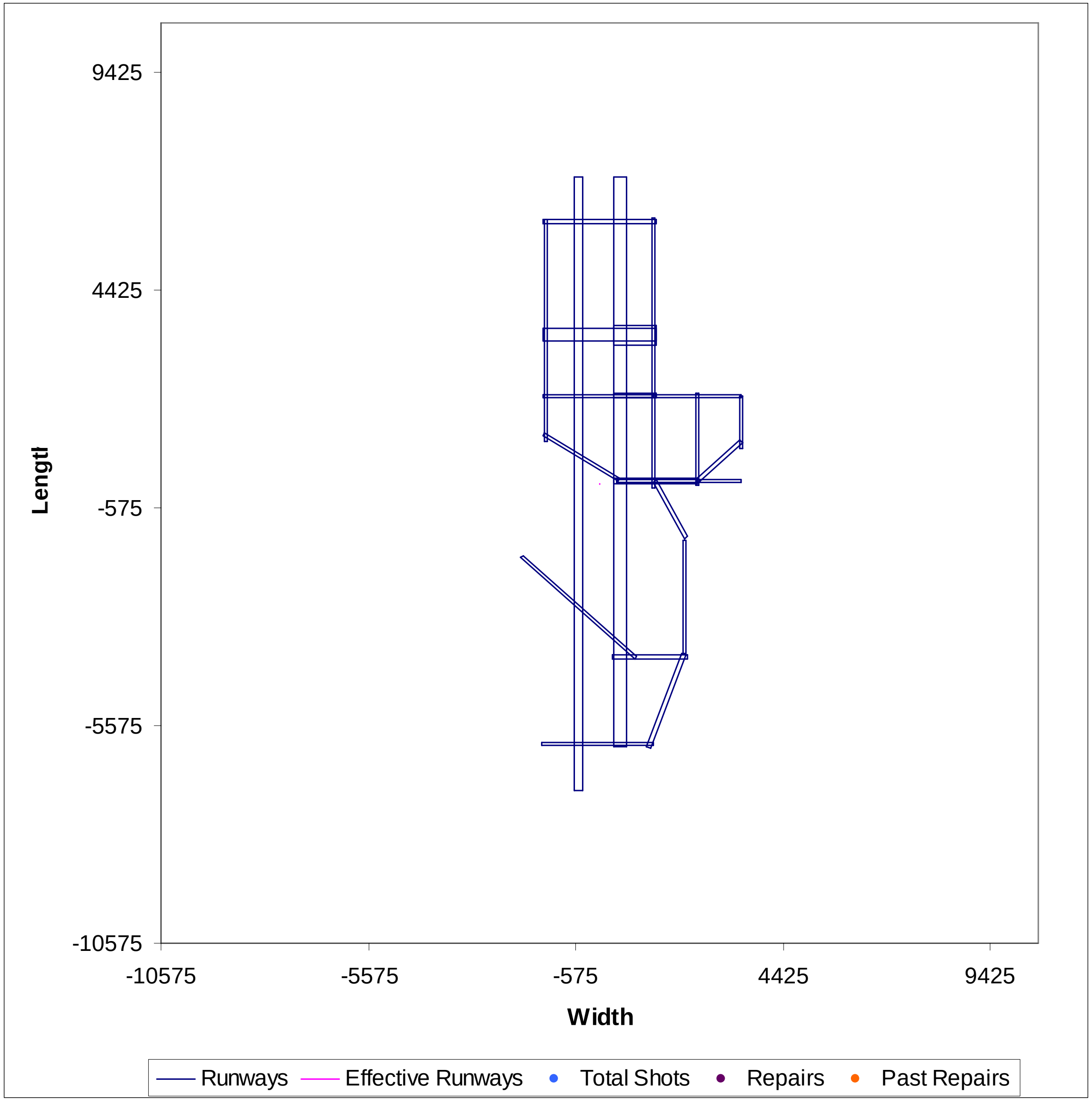


SLICR Model Example – Parallel Runways

OSD/PA&E



SLICR Model Example – Complex Airfield



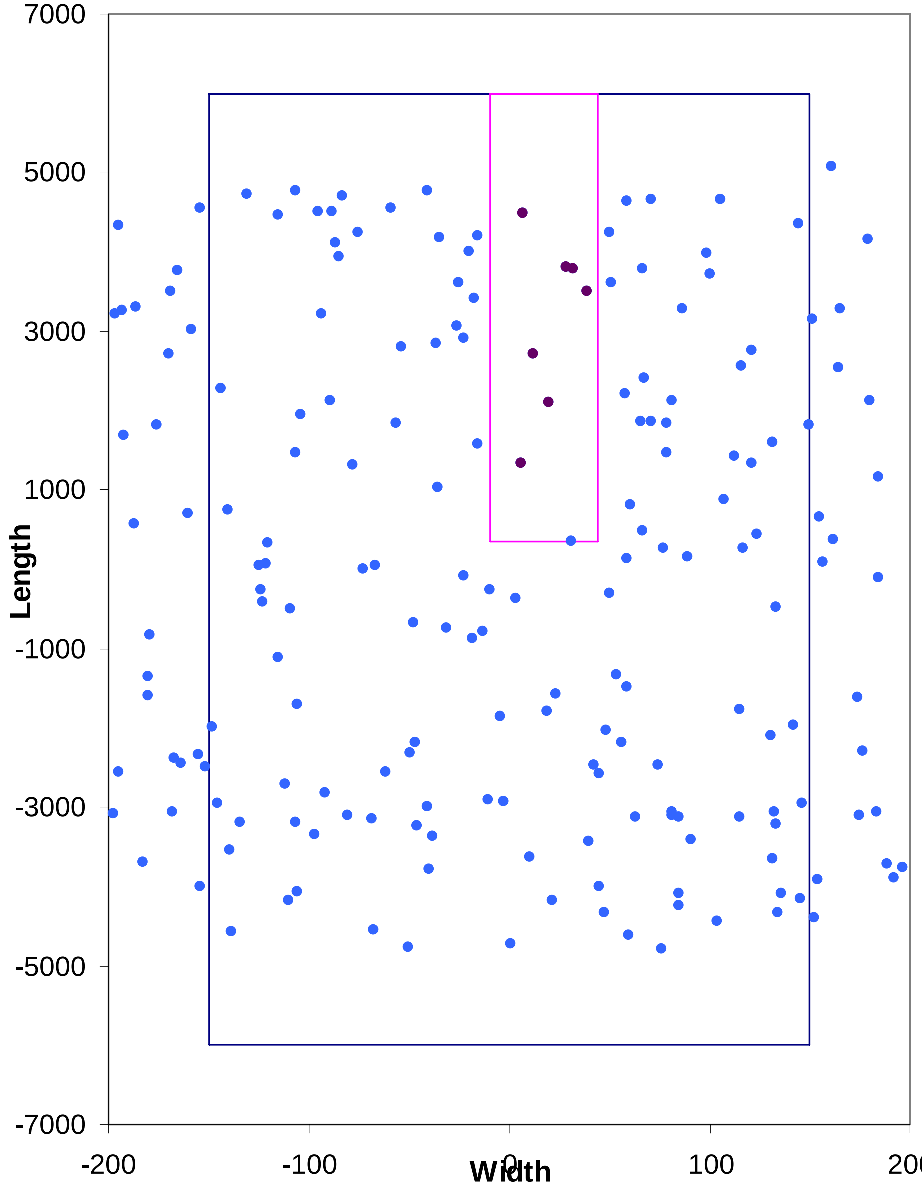
Contents

SLICR Model Description
Repair Methodology

- Three methods for calculating repair time
  - Repair minimum number of craters
  - Repair average number of craters
  - Repair accessible strip
- Repair times based on Air Force engineering runway repair data for craters less than 20 ft.
  - Crater evaluation – 3min per crater
  - MOS selection – 30 min
  - Unexploded ordinance/FOD removal – 60 min
  - Crater repair – 65 min first crater, 35 min each additional crater

Repair Time – Minimum Repairs

- Evaluate all craters
- Select the **fewest craters** to repair a section meeting the MOS criteria
- Clear unexploded ordnances
- Repair craters



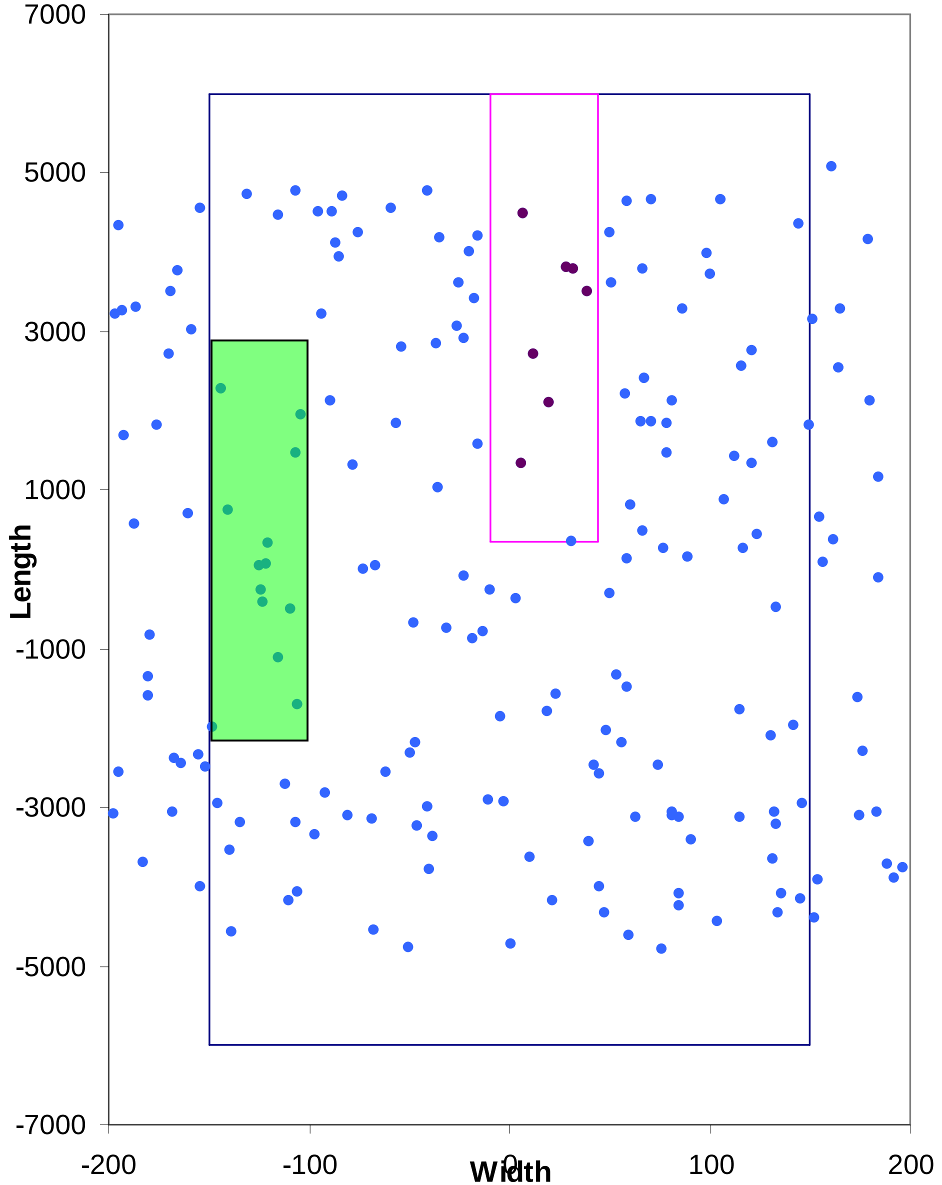
Repair Time – Average Time

Evaluate only the craters in an **average region** that meets the MOS criteria

Clear unexploded ordnances

Repair the average number of the craters for the given MOS area

NOTE: the number of craters to repair is defined as the density of craters on the runway multiplied by the MOS area



Repair Time – Most Accessible

Evaluate all craters in a region six times the MOS criteria.

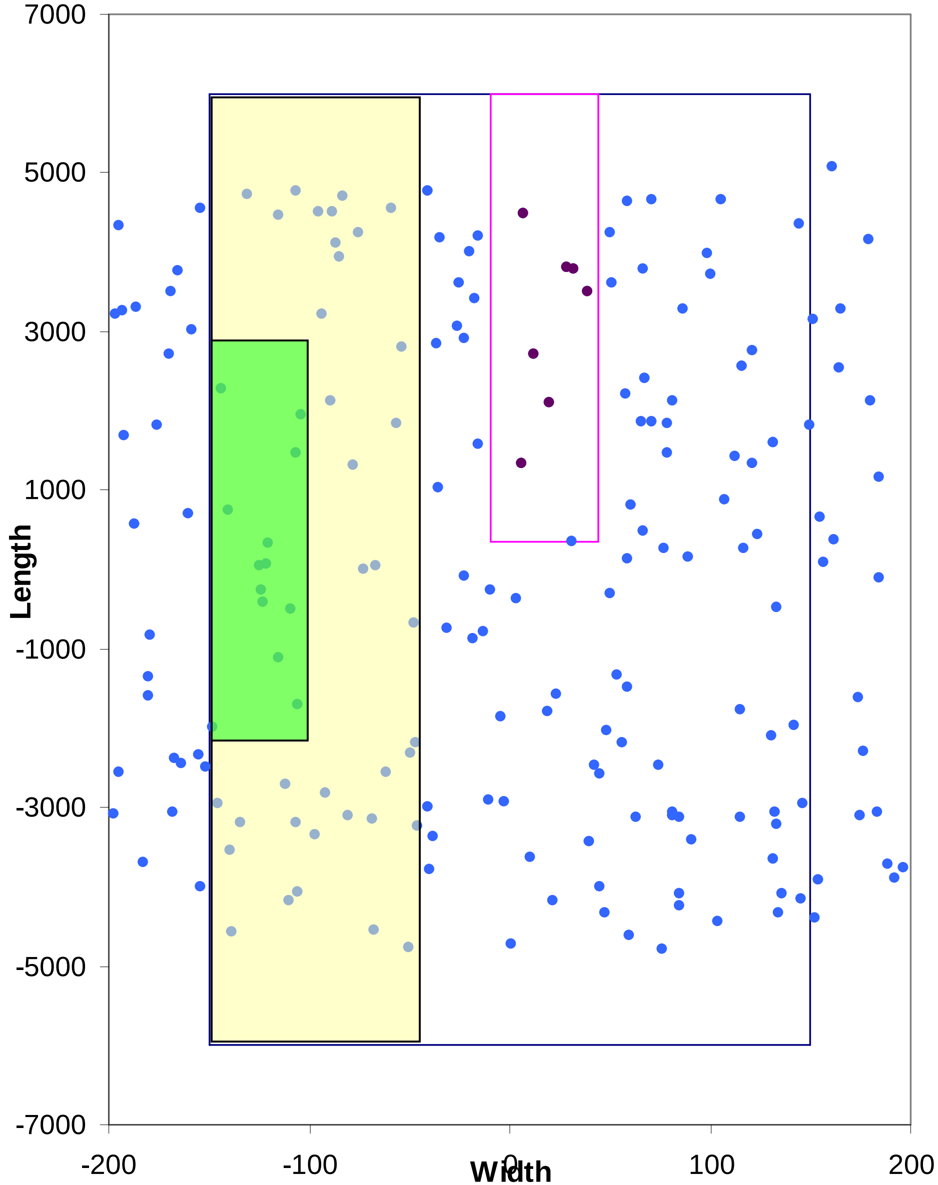
NOTE: Usually this will be a region of the runway that is most accessible by crew and aircraft.

Repair the average number of the craters for the given MOS area

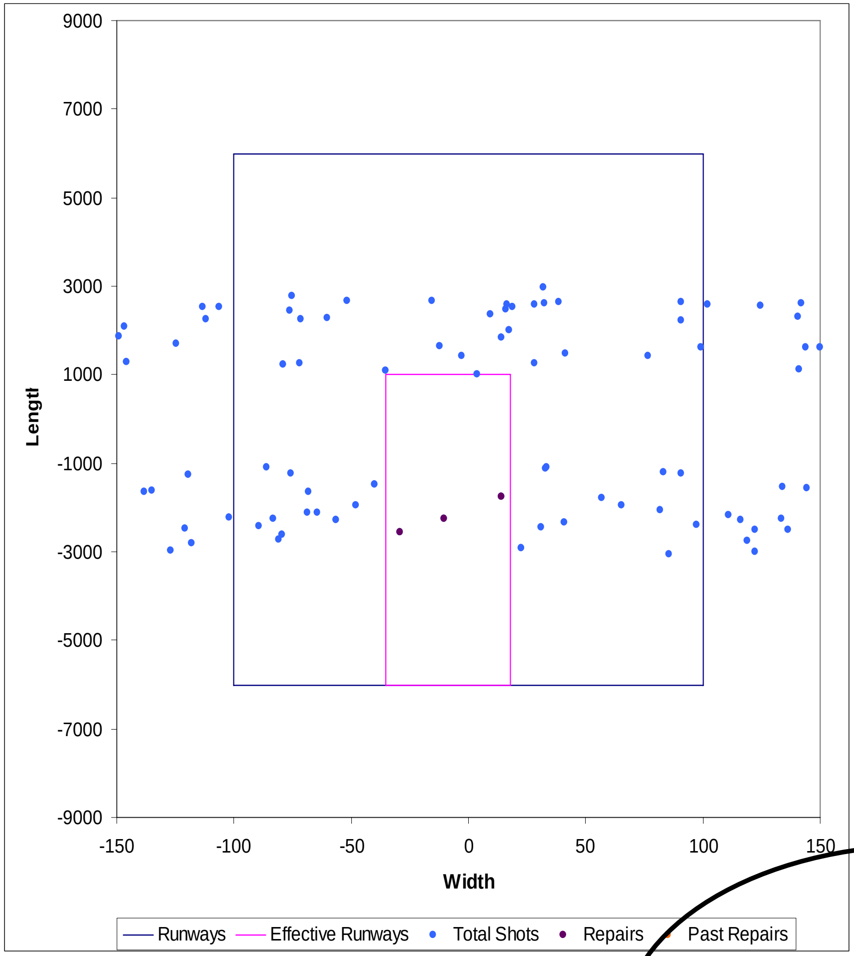
Clear unexploded ordnances

Repair craters

NOTE: the number of craters to repair is defined as the density of craters on the runway multiplied by the MOS area.



Repair Time – Outputs



Weapons per Cut	Pk	Ave. Repairs	Std. Dev. # R	Ave. Subm. on T.	Std. Subm. on Tgt	Min Repair Time	Ave Repair Time	Acc Repair Time
1	0.24	0.3	0.46	18.47	3.89	212	196	220
2	0.85	1.6	1.01	37.12	5.43	304	272	317
3	0.98	3.2	1.31	55.35	6.70	428	348	414

Contents

Missile Defense

Model missile defense by degrading the threat missile reliability. The effective reliability (R_{eff}) can be calculated by

$$R_{eff.} = R\frac{\frac{m}{n}(1-P)^{n}+\left(s-\frac{m}{n}\right)}{s}$$

R_{eff} = Effective threat missile reliability
R = Native threat missile reliability
P = Interceptor effectiveness
m = Number of interceptors used
n = Number of interceptors per threat missile
S = Number of threat missiles

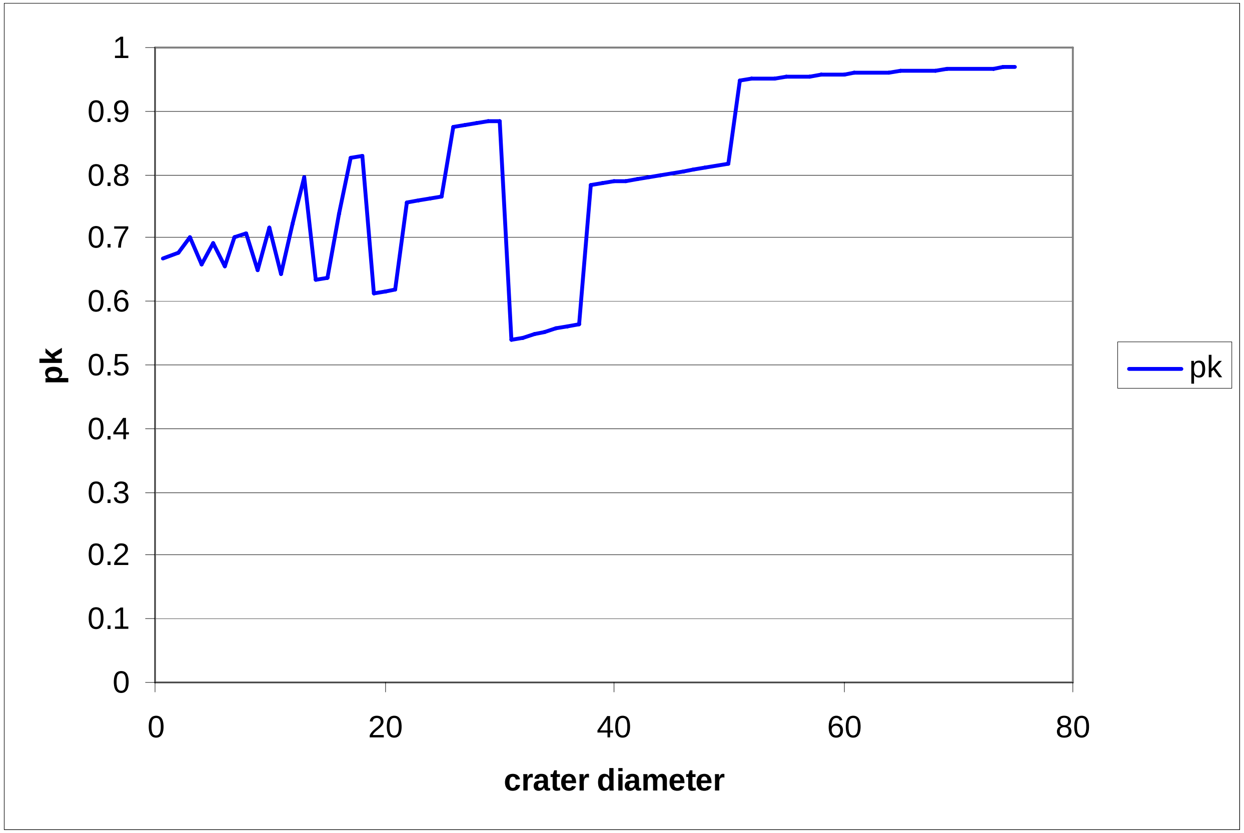
SLICR Model Point of Contact

Mr. Frank Lewis
OSD/PA&E/GPP/TACAIR
Email :frank.lewis@osd.mil
Phone: (703) 695-2606

Model Demonstation

BACKUP SLIDES

Pk as a function of crater diameter



Runway Width = 150
Minimum Width = 50
Dispersion = 1000
Num Penetrators = 70
CEP = 150